The Rt Hon'ble Sir Henry Storks G.C.B.
with the Author's Compliments

ADDRESS

OF

CHARLES HUTTON GREGORY, Esq.,

ON HIS ELECTION AS

President

OF

THE INSTITUTION OF CIVIL ENGINEERS,

Session 1867–68.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS,
STAMFORD STREET AND CHARING CROSS.
1868.

Bt. from Baldwin

ADDRESS

OF

CHARLES HUTTON GREGORY, Esq.,

President

OF

THE INSTITUTION OF CIVIL ENGINEERS,

ON TAKING THE CHAIR, FOR THE FIRST TIME, AFTER HIS ELECTION,

January 14, 1868.

In addressing you, Gentlemen, as I now do for the first time as President of the Institution of Civil Engineers, I feel deeply the honour you have conferred upon me by electing me to be the successor of the many distinguished men who have hitherto occupied this chair. If I can never hope to leave behind me such a reputation as they have achieved by high attainments and great works, my heartiest efforts will be devoted to emulating their example, by presiding with courtesy and fairness over your deliberations, and by promoting, by every means in my power, the interests and progress of the profession, in the earnest hope that, by your kind support, and the cordial co-operation of my colleagues in the Council, this Institution may be maintained, during my tenure of office, in undiminished usefulness and honour.

Fifty years ago, on the 2nd of January, 1818, this Institution was founded, its members then being only six in number. On the 21st of March, 1820, Thomas Telford, our first President, in his inaugural address, referred to the nature of the Institution and its probable future usefulness, and pointed out the significant fact, that while, in foreign countries, such Institutions depended on Governments for their support, in this country their existence and

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[illegible] requesting him to [illegible] the Institution of Civil Engineers and to give [illegible] Civil Engineer [illegible] in order that this description [illegible] in a Petition to the Attorney-General, in application for a Charter."

At the following meeting of Council on January 4th, 1828, the Secretary [illegible] communication received from Mr. Tredgold, [illegible] the Minutes:—

[illegible]tion of a Civil Engineer,

[illegible] Tredgold, Hon. M. Inst. C.E.

[illegible] art of directing the great sources of [illegible] convenience of man; being that [illegible] important principles of natural [illegible]able degree, realized the antici[illegible] aspect and state of affairs in the

whole world. The most important object of Civil Engineering is to improve the means of production and of traffic in states, both for external and internal trade. It is applied in the construction and management of roads, bridges, railroads, aqueducts, canals, river navigation, docks, and storehouses, for the convenience of internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses; and in the navigation by artificial power for the purposes of commerce.

"Besides these great objects of individual and national interest, it is applied to the protection of property where natural powers are the sources of injury, as by embankments for the defence of tracts of country from the encroachments of the sea, or the overflowing of rivers; it also directs the means of applying streams and rivers to use, either as powers to work machines, or as supplies for the use of cities and towns, or for irrigation; as well as the means of removing noxious accumulations, as by the drainage of towns and districts to prevent the formation of malaria, and secure the public health. This is, however, only a brief sketch of the objects of Civil Engineering, the real extent to which it may be applied is limited only by the progress of science; its scope and utility will be increased with every discovery in philosophy, and its resources with every invention in mechanical or chemical art, since its bounds are unlimited, and equally so must be the researches of its professors.

"The enterprizing Hollanders towards the close of the sixteenth century first separated Civil Engineering from architecture, under the title of hydraulic architecture; their example was followed in France towards the end of the seventeenth century, and soon afterwards was systematized in the great work of Belidor on Hydraulic Architecture.

"One of the great bases on which the practice of Civil Engineering is founded is the science of hydraulics; every kingdom, every province, every town has its wants, which call for more or less acquaintance with this science. Water, which is at once the most useful of the necessaries of life, and the most dangerous element in excess, when limited by the laws of this science is rendered the best of servants; the rolling cataract which spends its powers in idleness may be directed to drain the mine, to break the ore, or be employed in other works of labour for the use of man; the streams are collected and confined in canals for inland traffic; harbours are formed to still the raging of the waves of the ocean, and offer a safe retreat to the storm-driven mariner; and ports are provided with docks, to receive the riches of the world in security: hence arose the term hydraulic architecture; but it was too limited; the various applications of water had rendered the natural supplies ir adequate to the wants of man, till he discovered that, combir

with heat it formed a gaseous element endued with energies not less powerful than the falling cataract; its steam, confined and directed by science, became a new source of power, which in a few years altered and improved the condition of Britain, and we are every day witnessing new applications, as well as the extension of the older ones to every part of the globe."

Many of you will recognize some of the expressions of this description, which has, in fact, been abridged in our Charter; but I make no apology for giving it you entire, believing that you will appreciate its comprehensiveness, and its beauty.

Eloquent and comprehensive as the words of Tredgold were, even his almost prophetic vision forty years ago did not take in the whole of that field of usefulness now open to us, and which ever grows wider by cultivation. The contributions of science have kept pace with the growing wants of the age. Metallurgy has worked out a revolution in the treatment and application of metals; chemistry has pointed to the purification and utilization of the sewage of towns, and the relieving rivers of pollution; hydraulics have led to projects for supplying cities with water from remote mountains; electricity speeds the "winged word" in "a girdle round about the earth" more quickly than fairy magic in the dreams of poets.

If exact science has led the way, the members of this Institution have not been slow to follow with constructive science; our Proceedings are rich with the records of works great in extent or interest, but some remain to be described. The Thames Embankment, the completion of the great Sewage Works and Outfalls, the Millwall Docks, various new or modified forms of Floating Docks, the Mont Cenis Railway, the successful submerging of the Atlantic Telegraph, the latest Iron Ships, the important works of the various Metropolitan Railways, and the Public Works which have been carried out in our Colonies;—these and other undertakings recently completed, or in course of construction, will, it is to be hoped, become soon the subject of Papers and discussions.

In illustration of what has been recently done in our Colonies, I may mention that Victoria, with an annual revenue of about £3,000,000, spends about £300,000 in Roads, Bridges, and other

public works; Ceylon, with a revenue of about £1,000,000, spends about £230,000; Mauritius, with a revenue of about £650,000, spends about £70,000; and the Cape, with a revenue of about £860,000, spends about £50,000. In addition to these sums, and irrespective of the Cape Railway, executed by a Company with a Colonial Guarantee on a fixed capital, the following sums have been raised and laid out within the last few years for the construction of Railways: by Victoria £10,000,000, by Ceylon £1,750,000, and by Mauritius £1,430,000. These railways have been executed by the respective governments, without the intervention of companies; they have not been opened long enough to develop their traffic, but there is reason to believe that they will pay more than the interest on the money borrowed. It should be stated that of the sum set down as spent upon railways in Ceylon, only £800,000 was borrowed, the remainder being produced by a tax on coffee and by ordinary revenue.

At a time when so much criticism is directed to the management and effects of Railway Enterprise, it should not be forgotten how much of the present evil has arisen from unprofitable works forced on Companies by public opinion, and from the freedom with which Parliament has sanctioned competing lines. While we may deplore the individual losses which have arisen from these causes, and from over-speculation, we may recall, on the other hand, the great social and material benefits which railways have conferred on the country. Wisely or unwisely, upwards of four hundred millions have been expended upon our railways in about forty years. Irrespective of the saving of time, and the vast increase of profitable commerce to which they have given rise, it has been estimated that the saving to the public in the cost of transport alone, by the use of Railways, as compared with that by other means of conveyance, if they had been equal to such an amount of traffic, would be measured by an interest of no less than 15 per cent. on this great outlay.

The present depression of commercial enterprise may for a time check the progress of great Engineering operations, but perhaps it may give to corporate bodies a good opportunity for engaging the services of engineers in designing and carrying out many important sanitary works; and lead to the study of the numerous localities where low lands are now inadequately drained,

but prior to this time the construction of firearms was really carried on by small manufacturers, who each made only one separate part, one for locks, one for barrels, one for bayonets, &c., the gunmaker being, in fact, little more than a setter up; and the Government, after obtaining by contract the separate parts of their muskets, excepting barrels and some small parts, from separate manufacturers, put them together at their own works at Enfield.

In 1853, Mr. John Anderson, M. Inst. C.E., Engineer to the Board of Ordnance, proposed the construction and equipment of a Government manufactory, in which, by the use of complete machinery, all the processes for the production of small-arms should be carried on successively to completion. In 1854 the subject was considered by a select committee of the House of Commons, and the adoption of machinery, as recommended by Mr. Anderson, was advocated by Mr. Jos. Whitworth, M. Inst. C.E., Mr. James Nasmyth, General Tulloh, R.A., and other Officers and Engineers; and, in spite of the views of those whose habits or prejudices led them to oppose a new system, the committee recommended a partial trial, which issued in the establishment of the present Small-arm Factory at Enfield.

This new factory, stocked with improved machinery, founded on that already in use in the United States Arsenals at Springfield and Harper's Ferry, and made partly in America and partly in England, was set to work in January, 1857, under the direction of Colonel Manley Dixon, R.A., the present Superintendent of Small Arm Factories, in the construction of small-arms generally, but particularly of the Enfield rifle of the pattern of 1853, which, with trifling modifications, is the long rifle now used in our army, where not superseded by the Snider breech-loader. The machines used at Enfield are to a great extent varieties of copying-machines, in which a standard model is reproduced by a revolving cutter, in wood or metal as the case may require. The different parts, as produced, are checked with templates and gauges, and finally the finished parts, stock, lock, barrel, bands, bayonet, plates, screws, &c., find their way in numbers to an "assembler," who, furnished with a screwdriver and a chisel, takes the parts up indiscriminately, and puts them together; and so entirely interchangeable are the parts

found to be, that a payment of $3d{\cdot}29$ for each rifle put together gives the workman wages of about 50*s.* per week.

The long Enfield rifle consists of 53 parts, and passes through about 740 processes of manufacture. These processes are multiplied so as to simplify each operation, to divide the labour, and to require mostly only a cheap class of workmen. All parts, including the stock, are issued for repair in a finished state, and any damaged part in a rifle in use can at once be replaced by a corresponding part without any fitting.

Up to the present time the Government has had no contract for interchangeable arms, excepting one for 30,000 with the London Armoury Company. The Birmingham Small-arms Company has, however, lately made interchangeable short rifles for the Turkish Government The cost of non-interchangeable long Enfield rifles with bayonets, under a contract made in 1859, was £2. 18*s.* 6*d.* each, to which must be added the cost of the stock 2*s.* 6*d.*, and viewing expenses 3*s.*, bringing the total cost to £3. 4*s.* 0*d.* each. It is stated that the average cost of the long Enfield rifles made at the Government Factory, including an allowance of 5 per cent. on the cost of buildings and machinery, for depreciation, has averaged about £2. each. In 1859 a contract was entered into for short Enfield rifles, which, complete, and including stocks and viewing expenses, cost £4. 14*s.* 0*d.* each. The cost of subsequently producing the same weapon at Enfield is stated to be £2. 14*s.* 0*d.* each. Neither interest on capital nor profit are included in the Government estimates here quoted.

It has been estimated that the improvement arising from the accurate work produced by good machinery, coupled with that arising from better ammunition, has resulted in reducing by 50 per cent. the mean deviation in rifle shooting. The old smooth-bore musket was considered to make good practice if, at 100 yards, 75 shots in 100 hit a target 6 feet square. With the present service rifle and ammunition, 100 shots can, at the same range, be placed in a space of 6 inches.

From January 1857 to December 26th, 1867, the total number of new arms made at Enfield was 616,828. The number of arms converted to breech-loaders on Snider's plan up to the same date, was 175,550. On April 1st, 1866, an order was sent to Enfield to

prepare for the conversion to breech-loaders of 40,000 arms; on July 1st this order was enlarged to 100,000; between July and September 10,000 converted breech-loaders had been sent to Canada, and by April 1st, 1867, the whole 100,000 had been supplied. The cost of the alteration of old machines and the supply of new ones for the purpose of the conversion, has nearly reached £10,000, which, divided over 200,000 arms, would come to 1*s.* each. The cost of converting to the Snider breech-loader, including the above sum and depreciation on buildings and plant, is said to be about 16*s.* 3*d.* per arm. With the present machinery, Enfield is capable of turning out about 130,000 new arms annually.

It is said that even now the Enfield factory stands alone in England, and it is believed, in Europe, in the fact that every part of the arm produced there, from first to last, is made on the premises.

The advantages claimed for this central Government establishment are, that it prevents the country from being dependent for arms on private factories, that it maintains a standard of excellence, and can afford to develope the best mechanical improvements, for insuring accuracy, interchangeability, and cheapness. It must be admitted that this establishment has well fulfilled its promise; it has shown great and elastic powers of production; it turns out arms which have the great merit of interchangeability, and which, for soundness and excellence of work, cannot be equalled by the military arms of any other country; and it has, although only by slow degrees, led to the adoption, by a portion of the gun-making trade, of the system of concentration and of copying-machinery.

The Crimean war has given the greatest impulse in modern times to changes in the material of war and the means of defence. Roused from a long interval of repose, undisturbed by any great war, the public interest was at once directed to every measure which was proposed to increase our power for offence or for defence. During the years 1854 and 1855 the Government were besieged by inventors, and the Ordnance Select Committee, to whom their inventions were referred, had often to consider and report on twenty or thirty projects in each week. As might be supposed, a

large number of these schemes were wild and impracticable; ungovernable torpedoes and submarine rams, vied with balloons which were to carry shells of tons in weight; ships, in the fore-part of which were to be framed guns of 100 feet long, were to be fitted with a moveable stern for carrying ammunition, and which was to be detached like the limber from a field gun, while the ships of the enemy were to be burnt with naphtha floating on the sea around them. But amidst much that was useless, many practical men were bringing their minds to bear on the great changes which applied mechanics might work out; and if it be no matter of surprise that some of the most valuable propositions came from Engineers, it is due to those Officers of the Government whose departments came officially under my notice, to bear my testimony to the zeal and intelligence with which they applied themselves to the public service. While the Select Committee fairly and honestly weighed all propositions laid before them, the officers of the gun factory, the carriage factory, the laboratory, and other establishments, were actively employed in the introduction of new machinery, and in many improvements of great and permanent value, with which, then or since, the names of Generals St. George, Lefroy, and Tulloh, Colonels Wilmot, Boxer, Askwith, Dixon, Campbell, and Clarke, and Messrs. Abel, Anderson, Fraser, and others, have become honourably connected.

I will not attempt to follow out all the improvements to which that period gave rise, but will refer shortly to those most connected with our profession, viz., the production of heavy armour plates and large guns, with their consequent results.

While suggestions had been made and partial experiments tried with a view to the use of iron for defensive purposes, prior to the Crimean war, the credit of the first great trial of a practical nature is due to the Emperor of the French, who built three floating batteries cased with thick iron plates, which were engaged in the attack of the Allies on Kinburn, on October 17th, 1855. These batteries were exposed, unsupported, to a heavy fire at a range of 700 yards for about three hours, and although some casualties occurred from shot and shell entering the large old-fashioned port-holes, the vessels received very little injury. From

this date the public attention was drawn more closely to the protection of ships of war by armour plating, and various experiments were made in this country, among which were the trials, towards the end of 1858, of the 'Meteor' and 'Erebus,' iron-cased floating batteries, and of an iron shield fixed to the side of the 'Alfred,' against which, for the first time, the powers of rifled ordnance were brought to bear.

It soon, however, became apparent that the subject of the use of iron for this novel purpose was so complicated by considerations of a mechanical character as to demand a more searching technical investigation than it could receive at the hands of purely military or naval authorities; and at the end of 1860 the Government determined to submit the whole matter to the investigation of a mixed Special Committee, which was appointed in January, 1861.

This Committee consisted of six members:—Sir John Hay (Chairman) representing the Navy, Major Jervois, the Royal Engineers, and Colonel Henderson, the Royal Artillery; and to these were added three members whose qualifications were of a more technical character, viz., the eminent metallurgist Dr. Percy, F.R.S., and two of our own profession—Dr. Fairbairn, M. Inst. C.E., and Dr. Pole, M. Inst. C.E., whose names are too well known in this room to render necessary any remark on their qualifications for the investigation in question.

The first step taken by the Committee was to collect, by oral evidence, the opinions of a great number of engineers and others practically acquainted with the manufacture and use of ironwork; and the great diversity of the views thus gathered showed the obscurity in which this novel application of material was involved.

The Committee then commenced their experiments, beginning with trials of simple iron plates of various sizes and thickness, and manufactured in different ways, and they arrived early at certain general deductions on points which had previously been uncertain; for example, they reported that out of many varieties of material tried the best for resisting shot was wrought iron;—that this should be of the softest and toughest possible quality, any hardness or steely character being very prejudicial;—that, *cæteris paribus*, the resisting power, up to a certain limit, varied nearly as the square of the thickness;—that corrugations, bosses, or irregularities of sur-

face were disadvantageous, plain surfaces being best;—and that the plates should be as large, and with as few joints as possible.

The Committee further proceeded to examine, and test by actual trial, various constructions of iron defences, both for ships and for land fortifications, the former however receiving their principal attention. This work occupied them for more than three years, during which time a great number of experimental targets were made, on a great variety of principles, and were thoroughly tested with artillery at Shoeburyness.

These trials, on so thoroughly practical a scale, led to experience of great value, not only as to the strength and capability of the material generally to resist shot from certain guns, but also as to the modes of fastening, the effect of various kinds of backing, and the general principles which should guide iron defensive construction. But perhaps the most valuable result of the Committee's labours, or at any rate, the result most interesting in an engineering point of view, was the great improvement effected through their means in the manufacture of iron in large masses. The Committee from the first adopted the principle of making all their trials and results open to the inspection of all parties legitimately interested in the subject. The makers of iron plates were especially invited to witness the experiments, and to study the results produced, being afforded at the same time the benefit of all the information in the Committee's possession which could throw light on the subject. Independently of the public satisfaction given by this open system, which, I believe, has been subsequently followed in other ordnance experiments, these opportunities were of the greatest use to the iron-makers, for by no other means could they have obtained such complete insight into the nature of the problems to be solved, and the conditions necessary for their solution.

The iron-makers availed themselves willingly of these opportunities, and the result was strikingly marked in the improvement effected.

When the Committee began their labours, the manufacture of armour plates had only been attempted by one or two makers, and even in their hands was little more than tentative; the quality was very uncertain, and no great reliance could be placed on the resisting power of any plates above three inches thick. But during

three years' experience, many excellent makers had come into the field; the general average of quality became greatly improved and much more certain, and plates 5 in. and 5½ in. thick, could be produced with their full resisting power.

In the middle of 1864, the Iron Plate Committee was dissolved, and their functions re-transferred to the military and naval authorities. I cannot but think this step to have been injudicious; for although doubtless the Government of the day thought that the question had arrived at such a stage of development as no longer to require special technical treatment, yet they omitted, I think, the important consideration that the comparative question between guns and iron defences was, then at least, in a high degree progressive, and that, if improvement was to go on, the technical treatment of the subject must still be necessary; and experience has shown this to be true.

The Committee have left behind them full records of everything they did, containing, in four large volumes of Reports and Proceedings, a mass of information of great interest and value, and forming a compendium of almost all that was then known on the subject. It is to be regretted that these volumes are not published. I find it on record in our correspondence, that one of the members of the Committee, Dr. Pole, obtained the special permission of the Government to give to this Institution a summary of the contents of these volumes, and I take the opportunity of reminding that gentleman that his undertaking to that effect has not yet been fulfilled.

The attention of the Iron Plate Committee was principally directed to plates to be applied to ships: recent circumstances have led to the temporary re-appointment of a Government committee on iron plates, similarly constituted to the last, and comprising the same Civil members; and it is to be hoped that their labours may not be prematurely checked, but that they may be allowed to pursue their investigations on the application of iron plates to land forts, so far as to afford safe data to our Royal Engineers, and to prevent the serious evils which might result from the large application of iron to our Fortifications on any system which had not been fully investigated, and thoroughly tested. I also venture to submit that the hands of the Committee would be

strengthened by the addition of a naval architect experienced in the building of armour-clad ships.

During the last few years the size and thickness of iron plates have greatly increased. The plates of the 'Warrior,' constructed in 1861, were 4½ inches thick; those of the 'Bellerophon' are 6 inches thick; while the 'Hercules' has plates of 8 inches, and 9 inches thick at the water-line. In France, the plates used for the navy have been increased to a thickness of 15 centimetres, or 6 inches, and the 'Marengo' and the 'Ocean' will have at the water-line plates of a thickness of 20 centimetres, or nearly 8 inches. A wrought-iron plate, 14 feet long and 6 feet 6 inches wide, and 15 inches thick, has been prepared for trial at Shoeburyness. Some of the principal English manufacturers (Messrs. J. Brown and Co., C. Cammell and Co., and the Millwall Iron Company) now offer to roll plates about 20 feet long, 6 feet wide, and 15 inches thick; but it may be doubted whether plates of such thickness and size can at present be so perfectly manufactured as to give their full proportionate resistance: the production of thoroughly sound and uniform plates of large size, 10 inches thick, may, however, I believe, be regarded as an accomplished fact.

Concurrently with the production of iron plates for purposes of protection there has been a great increase in the size and destructive power of Ordnance. Some of the earliest guns known were compound, or built guns. In the Royal Military Repository at Woolwich is one of the time of Henry VI. (1422 to 1461), composed of two circles of longitudinal iron bars, imperfectly welded, and close hooped with iron rings, with a bronze powder-chamber inserted in the breech:—indeed for guns of any size a built gun was a necessity at a period when the manipulation of metals in large masses was a rare and difficult operation. The great bombards at Edinburgh and Ghent, closely similar to one another in design, and those of English manufacture at Mont St. Michel, are notable instances of large built guns, which, however, could probably not have stood one full charge of powder of modern strength.

The developement of art in the fifteenth century, which revived large bronze castings for ornamental purposes, led, perhaps, to the

use of bronze for guns. In the year 1543, in the reign of Henry VIII., Ralph Hogge is stated to have cast, at Buckstead, in Sussex, the first cast-iron guns used in England, but it was not until a much later period that cast-iron guns were largely used in England, or at all on the Continent. For many years before the Crimean war, brass and iron guns had been made with very little change of form; but when public opinion was drawn to the application of mechanical improvements to the production of guns of great size and strength, clever designs were brought forward by so many that I will not attempt here to give even a list, much less to assign to each its due proportion of merit; but the large wrought-iron "Horsfall gun" of the Mersey Company and the monster mortar of Mr. Mallet may be cited as two remarkable examples. The "Horsfall" was a smooth-bore gun, in one piece, weighing 21½ tons, and having a calibre of 13 inches; and it is now mounted at Tilbury Fort. Mr. Mallet's mortars were compound, weighing 41 tons, with a calibre of 36 inches, from one of which, with a charge of 70 lbs. of powder, a shell weighing 2,395 lbs. was thrown 2,759 yards, burying itself 8 yards in the ground on its fall. The limited practice with this mortar was interrupted by the fracture of a tie-bolt; but it is greatly to be regretted that no further experiments have been made with it, or with the second piece, which has never been fired.

The remembrance of the discussions held in this room will recall the names of Sir W. Armstrong, M. Inst. C.E., Mr. Whitworth, M. Inst. C.E., Mr. R. Mallet, M. Inst. C.E., Mr. Longridge, M. Inst. C.E., Captain Blakely, R.A., and others, as having either investigated the scientific principles which should direct the construction of great guns, or applied those principles to various forms of construction. You will all remember that in 1860 breech-loading rifled guns were the order of the day, and that neither brass nor cast iron, as materials, were considered to fulfil the necessary conditions. The designs which had earned the greatest consideration, both from the Government and the Public, had been produced by those two distinguished members of our body, Sir William Armstrong and Mr. Whitworth; and as far as the construction of the guns was then concerned, the leading points of difference were, that while the Armstrong gun was built up of several rings or tubes

of coiled wrought iron shrunk over one another, and over a steel lining, with small grooves to take a soft coated projectile, the Whitworth gun was built up of tubes of mild steel, forced with a taper over one another, and over a steel lining, the bore being polygonal, with a hard mechanically-fitting projectile.

The details of both systems were subsequently more or less changed, and in January 1863, a special mixed Committee was appointed to make full experiments, and to investigate, with two calibres, viz.: 12 pounders and 70 pounders, the comparative merits in construction, endurance, range and accuracy, and in fact, in all the qualities which a gun should possess. The investigation was completed in April 1865: the information collected showed, in both systems, results as to structural strength, and efficacy and accuracy of fire," which had not been previously attained; and while it was not in all respects conclusive as to the comparative merits of the guns, it pointed out more prominently than ever the perfection to which artillery might be brought by the application of Engineering skill.

In 1859, Sir William Armstrong was appointed Superintendent of the Royal Gun Factories, and, assisted by Mr. Anderson, established the new workshops for the construction of compound guns, which were fitted up with machinery of great power and accuracy, specially designed for dealing with large masses of metal, and for ensuring precision of manufacture in putting together the various parts of the Armstrong gun, which practically became the gun of the service.

In 1863, Sir William Armstrong resigned his office, which has since been filled by Colonel Campbell, R.A., with Mr. R. Fraser, M. Inst. C.E., as his executive assistant.

Irrespective of breech-loading, which has been abandoned in this country for heavy guns, and of rifling, in which the original mode has been to a great extent superseded by larger grooves to guide soft metal studs fixed on a hard metal projectile, the gun now generally manufactured for the service has undergone considerable structural changes, the most material one being the diminution of the number of parts, and the substitution of outer coils of fibrous Staffordshire iron for coils of the best Yorkshire iron, tough steel being still maintained for the lining, as best resisting surface

wear. In the former type of gun, there was a forged breech-piece over the breech end of the steel lining tube, and, according to the size of the gun, a greater or less number of coiled tubes, carefully and successively fitted on. The pattern at present in use for all guns consists of only four pieces:—viz., 1st, the steel barrel or lining, 2nd, a coiled tube over the barrel, extending from the muzzle nearly to the trunnions; 3rd, the breech coil, consisting of three coils in alternate directions, welded together, with a trunnion piece welded on, the whole piece shrunk on over the breech of the barrel, and lapping over the front coil; 4th, the cascable. It is considered by the present authorities that the diminution in number of parts leaves the gun less liable to injury by accident and less dependent upon perfection in manufacture, and that practically an equal amount of strength is obtained; while it is held that a fibrous iron is to be preferred as more workable for coils, and as giving out its greatest strain over a greater distance than the best Yorkshire iron, which, while stronger statically, is considered not to yield so far before fracture. It is stated that this change has diminished the cost of production by 35 or 40 per cent.

The heaviest projectile thrown by any gun in the service prior to 1854, was the 200 lb. shell of the 13 inch mortar.

The largest Armstrong gun hitherto constructed is an experimental one, which has a calibre of 13·1 inches, weighs 23 tons, and throws a shell of 600 lbs.

It is intended that future 12 inch guns shall have a weight of 25 tons.

The 11 inch gun lately constructed weighs 23 tons, and the weight of the several parts are as follows:—The steel barrel, 5 tons 5 cwt. in the rough, 2 tons 16 cwt. finished; the muzzle coil, 2 tons 15 cwt. in the rough, 1 ton 16 cwt. finished; the trunnion and breech coil, 22 tons 6 cwt. in the rough, 17 tons 17 cwt. finished; the cascable 14 cwt. in the rough, 11 cwt. finished.

Two guns of Mr. Whitworth's, of 9 inch calibre, and weighing 15 tons, are about to be delivered for trial.

Prior to the mechanical improvements which have led up to the present rifled guns, the greatest distance to which a projectile was ever thrown from a smooth bore gun was not much over 6,000 yards, and the limit of bombarding range at high elevations, with

the 13-inch mortar, was 4,500 yards. With the modern ordnance projectiles have been thrown, with greater precision, to a range exceeding 10,000 yards: the guns of the service make good practice at 6,600 yards; in fact, much better practice than was formerly attainable at 3,000 yards.

At 1,000 yards the mean error of range of round shot from smooth bores may be taken as 43 yards, and that of rifled shot 19 yards; the mean error of direction (referred to the mean direction of all the shot), with round shot may be taken as 4·1 yards, and with rifled shot as 0·8 yard. At 2,000 yards the mean error of range of round shot may be taken as 60 yards, and that of rifled shot 21 yards; the mean error of direction with round shot 10 yards, and with rifled shot 21 yards. In other words, (the accuracy being inversely as the products of the errors,) the rifled gun is, in one case more than eleven times, and in the other, more than thirteen times as accurate as the smooth bore.

I have alluded to the structure and effects of British modern ordnance as giving another marked example of the advantage which has followed the application of Engineering skill, and the production of machines of special power, accuracy, and fitness, with which the names of Mr. Nasmyth, Mr. Whitworth, and Sir W. Armstrong are enduringly associated; and although I feel that a detailed comparison with the ordnance of other countries would perhaps be out of place, I may be allowed to express my belief that great as have been the advances made in the manufacture of heavy ordnance in France, in Prussia, and in the United States, neither have attained the certainty, the economy, or the perfection, of the productions of British Factories. But all our improvements will be of little avail in time of need, until smooth bores are much more largely replaced by rifled-guns. Meanwhile, for all practical purposes, we are almost unarmed in many of our so-called Defences, at home and abroad.

While such important changes have been effected in modern Ordnance, the advance recently made in Naval Construction is alike remarkable, and would have been equally impossible without the resources of modern Engineering.

Without attempting to trace the progress from wooden to iron ships, or all the steps by which our naval architects have passed

from the earliest to the most recent types of armour-clad ships, I propose to illustrate the general results by some comparisons between the structures of the 'Warrior' and the 'Hercules' as ships of 1860 and of the present period respectively. The 'Warrior,' of 6,109 tons, and 1,250 H.P., has armour-plating $4\frac{1}{2}$ inches thick, with teak backing of 18 inches, and an inner skin of $\frac{9}{16}$ths of an inch, the whole being backed by vertical frames, 10 inches deep, and about 2 feet apart. A length of 213 feet in the middle part of the ship is plated, and upwards of 80 feet at each end unprotected. The armour-plating of the mid-ship battery extends from 6 feet 3 inches below the load line to the height of the upper deck, while the ends of the battery are protected by transverse armour-plated bulkheads. The unprotected ends are divided into water-tight compartments, as a provision against the danger of shot-holes near the water-line; but there is no protection to the rudder-head and steering apparatus. The bow and stern guns on the upper deck are unprotected; and the only guns that can be fought under cover, are on the broadside, where they cannot be trained through an arc of more than 50° or 60°, a serious inconvenience with a vessel whose length of 380 feet is not favourable to rapid manœuvring.

The objections raised to a system which left so much of the ship unprotected, led, in ships of the 'Agincourt' class, and the converted wooden line-of-battle ships, to the adoption of complete armour-plating for the whole length of the ship, from the upper deck to a few feet below the water line; but as the increasing power of guns made it necessary that armour-plating, to be effectual, should have greater thickness and weight, it became evident that to continue complete protection would involve such increase in the size of a ship as to render her almost useless for manœuvring. These considerations led to the introduction of the arrangement now adopted for the broadside ships of our navy, which provides a protected battery amidships, shut in by armour-plated bulkheads, and a belt of armour for the whole length in the neighbourhood of the water-line. By this means, in addition to the battery, protection is given to the neighbourhood of the whole water-line, to the engines and boilers, and to the rudder-head and steering apparatus. The first example of this distribution of armour was its application, in 1862, in the conversion of the 'Enterprise,' a

wooden sloop, from the designs of Mr. Reed, chief constructor to the Royal Navy.

The 'Hercules,' of 5,226 tons and 1,200 HP., has armour-plating arranged on the same principle, with the important addition that besides the central battery on the main deck, 73 feet long, there are protected batteries, on the main deck, at the bow and stern, 20 feet and 8 feet long respectively. The lower edge of the armour is 6 feet below the load line; on the batteries it extends up to the upper deck, and along the belt it ends at the main deck. The armour about the water-line is 9 inches thick, thence up to the port sill of the battery deck it is 8 inches, and the remainder 6 inches. The teak backing varies from 10 to 12 inches in thickness, and the skin plating is in two thicknesses of $\frac{3}{4}$-inch each. The vertical frames behind the armour are 10 inches deep and 2 feet apart, with horizontal girders of about the same size, and at equal distances, placed outside the skin plating. Within this structure is a second wood backing, supported by a second series of skin plates and vertical frames, from the lower deck down to the lower edge of the armour. Before and abaft the central battery, there is iron plating below the planking of the main deck, as a protection from vertical fire where the armour only extends a few feet above the load-line.

The sides of this ship are recessed before and abaft the central battery, so that by means of embrasures in the armour-plated bulkheads, the foremost and aftermost gun on each broadside can be traversed on turntables, so as to fire at an angle of 15° with the line of the keel, while that line is commanded by the guns in the bow and stern batteries. The 'Hercules' is 8 inches wider in beam than the 'Warrior,' but 55 feet shorter, and of 883 tons less burthen. She will carry a smaller number of guns, but of much greater weight, so that in the particulars above given she has the elements of much greater power, both for offence and defence, while in the former quality she is, perhaps, inferior in some respects to a type of ship now on the stocks, such as the 'Invincible,' which has an upper-deck battery, to carry four guns, each of which can be fired either from the broadside or fore and aft.

To the proper use of armour-plating, iron ships have become a necessary condition; and in their construction the principles worked

out by our late Vice-President, Mr. I. K. Brunel, by which the different parts of an iron ship are made to contribute to its strength, have become of great value. Mr. Scott Russell, the late Mr. Miller, Mr. R. Napier, Mr. Samuda, and others of our Members have borne their share in modern improvements in iron shipbuilding, and with those naval architects who are not yet Members of our body, we claim professional brotherhood. No Member of this Institution is likely to overlook the increased power which our Navy has derived from the improvements in marine engines, in which Messrs. Maudslay and Field, Penn, Seaward, Rennie, Lloyd, Stephenson, Ravenhill, Humphreys, and others of our Members have taken so active a part; and the screw propeller was first practically introduced and subsequently brought to its present use by the labours of Members of our body.

Our Navy now possesses thirty-one iron-clad ships, and eight more are on the stocks, four of the existing ships being furnished with turrets, which are to be supplied to two of the new ones. Admitting that this number represents a formidable force, and that in structural qualities our recent ships are excellent in design and construction, and superior to those of other countries, it must be remembered that many of our ships are of doubtful strength; and you will probably be surprised to hear that the sum devoted to the construction of new iron-clad ships for the current year does not reach £900,000, being less than one-twelfth of the vote for the Navy, and barely sufficient to build three iron-clad frigates. If an Iron-clad Fleet be proper and necessary, surely this fact merits the gravest consideration.

In the construction or improvement of our existing Fortifications, it must be admitted that our profession can claim to have contributed comparatively but little. Our Past-Presidents, Mr. Hawkshaw and Mr. M'Clean, have been intrusted with the construction of the foundations for forts at Spithead and Plymouth, of which we hope in due time to receive the records. The use of iron plates for land defences has at present been little more than experimental; various mechanical appliances are however in contemplation or under trial, and iron armour is proposed for many of the sea and river forts, to several of which turrets also will be applied. It

cannot be denied that if much money had been laid out on works of this character with the information of only a few years ago, most of that expense would have been wasted; at the same time it may be suggested that improvements may come too late, if they are delayed in hopes of arriving at perfection.

Any notice of the principal applications of Engineering to the purposes of National Defence would be incomplete without some reference to Railways, which have always been expected to have an important bearing on modern warfare. They were admitted to be of great use in the movement and concentration of troops in the war in Lombardy in 1859; and in the German war of 1866 the Prussian government organized a special corps consisting of workmen and railway servants, under the direction of engineers and traffic officers, of which a division was attached to each "corps d'armée," to act, assisted by a military escort, in advance of the army, to repair any damages effected by a retreating enemy, to work lines occupied by the army, and, in case of retreat, to destroy lines in their rear.

Lieut. Hozier, in his admirable account of the Seven Weeks' War, admits the value of improved roads and railways in shortening the duration of campaigns, and especially in facilitating the transport of provisions, stores, and a siege train, and in relieving soldiers of heavy loads; but he considers that the power of railways for the transport of troops has been over-estimated; and that, in an enemy's country, railways have been proved to be of no use for the transport of the troops of the invader, during his advance, as the defending army breaks them up, and they cannot be repaired quickly enough. But, even independently of hostile obstructions, he says that experience proves that 10,000 men, equipped for the field, is the most that can be calculated upon to be moved per day, on a single railway; that when the Prussians were concentrating their army for the invasion of Saxony, it was rarely possible to send more than twelve trains a day, and that it required nearly ten days to move a corps d'armée of 30,000 men with all its "train" and baggage; and that even when the Austrian army was in retreat on Vienna, with little "train," and no baggage, it took them about six days to move 40,000 men.

I cannot but think that Mr. Hozier's views of the carrying capacity of railways might have been modified by the knowledge of what is done, on the volunteer field days, in this country; while his opinions on the uselessness of railways in an enemy's country, are apparently inconsistent with the experience of the last American war.

In that war railways and steamboats were found of inestimable advantage: the Reports of General Parsons, chief of rail and river transportation for the United States, show that he considered that the application of steam to transport had modified the art of war as much as the pursuits of peace, and he stated, in 1865, as the result of his experience, that "it is now practicable, on twenty-four hours' notice, to embark (by railway) at Boston or Baltimore a larger army than that with which Napoleon won some of his most decisive victories, and landing it within three days at Cairo, 1,200 miles distant, there embark it on transports, and within four days' more time, disembark it at New Orleans, 1,000 miles farther." In January, 1865, in the depth of a severe winter, the 23rd army corps was wanted for General Grant's operations before Richmond; after four or five days' notice, this force, consisting of 20,000 men, with all its artillery, and over 1,000 animals, was started from the Tennessee River, and moved nearly 1,400 miles in an average time not exceeding eleven days. The distance was about equally divided between water and railway transport, along rivers obstructed by fog and ice, and over mountains during violent snow-storms; with various interruptions, including thirty hours' detention from fog in the river, and, at one point, the unexpected delay of transferring the troops to boats of a smaller class; the railroad, meanwhile, being in the bad condition unavoidable in the severe winters of North America. Within seventeen days from the embarkation of the first troops on the Tennessee, General Parsons had the satisfaction of seeing the army quietly encamped on the banks of the Potomac, as fresh as when they started from the Tennessee.

During the war, 611 miles of railway in Virginia, Maryland, and Pennsylvania, 293 miles in North Carolina, and 1,201 miles in the military division of the Mississippi, giving a total of 2,105 miles, were more or less occupied by the United States authorities as military railways, under the direction of General M'Callum;

the government staff carrying on all the working of these lines, and repairs of works and rolling stock, and to some extent the rolling of rails, and the construction of new lines. At an early period a number of workmen, under competent engineers and foremen, were formed into a "construction corps," and stationed in detachments along any railway exposed to hostile attack, and stores were established, at intervals, to furnish the necessary supplies of rails, fittings, sleepers, and bridge timber. This corps became at last very experienced in the work of repairing damage. General McCallum's reports state that the Rappahannock River Bridge, 625 feet long and 35 feet high, was rebuilt in 19 working hours; that Potomac Creek Bridge, 414 feet long and 82 feet high, was built in 40 working hours; that Chattahoochee Bridge, 780 feet long and 92 feet high, was completed in 4½ days; that between Tunnel Hill and Resaca 25 miles of permanent way and 230 feet of bridges were reconstructed in 7½ days; and near Big Shanty, 35½ miles of permanent way and 455 feet of bridges in 13 days. The last of these remarkable operations took place on the line by which General Sherman was connected with his base, in his advance from Chattanooga to Atlanta; and, that the Military Railway Department, almost entirely through a hostile country, should have kept pace with the march of General Sherman, constructing and reconstructing the road in his rear, and ultimately have maintained the supplies of an army of 100,000 men and 60,000 animals from a base 360 miles distant, along a single line, exposed at all times to the attacks of an active and resolute enemy, is indeed a wonderful example of forethought, energy, patience, and watchfulness.

In our own country there can be no doubt that our railway system is one of our greatest elements of strength for national defence, while, in case of need, the skilled labour usually employed in peaceful constructions might be employed in works for our own protection, and for the obstruction of an enemy. In the year 1860 a proposition was addressed by Mr. C. Manby to Mr. Sydney Herbert, Secretary of State for War, offering the services of several members of this Institution for the formation of a Volunteer Corps, which should be ready for such work. The offer was favourably received, but no action was taken upon it until the year 1864, when General McMurdo, then Inspector General of Volunteers,

penetrated with the importance of the subject, gave it his best attention; Mr. McClean, our President at that time, and other members of the Council, became warmly interested in it, and ultimately, in January 1865, with the support of the Marquis of Salisbury, Lord Lieutenant of Middlesex, Earl de Grey, as Secretary of State for War, recommended to Her Majesty the establishment of the "Engineer and Railway Volunteer Staff Corps," "for directing the application of skilled labour, and of railway transport, to the purposes of national defence, and for preparing, in time of peace, a system on which such duties should be conducted." This corps, commanded by our Past-President, Mr. Bidder, consists of officers only, who must be Civil Engineers, Contractors, or Railway Officers. Its duties comprise the preparation, for the use of the Government, of reports on the railway transport of troops and their supplies, on the destruction and reconstruction of railways, the improvement of natural obstacles, and the making of artificial ones to impede the landing or advance of an invading force, and on topographical particulars connected with these subjects. These reports are confidential, but I may mention that they already contain much practical information with which the officers of the Government have been pleased to express great satisfaction, and that the calculations which have been made, in their preparation, by some of the most experienced railway managers, show that the completeness and the resources of our railway system would enable the whole regular and irregular army of the country to be moved upon any required lines of defence within a few days.

Before concluding, I ask your indulgence for a few suggestions with regard to the future.

And first I submit, that, however complete and efficient those Government establishments may be which produce our iron ships, our guns, and our rifles, and admitting the importance of maintaining their efficiency, it would be a mistake to extend their use so far as to cripple individual enterprise, and, by excluding all competition from without, to leave them no rivals now, and no assistants in time of need. By such competition many valuable inventions have been produced already, and may be expected here-

after; and the encouragement which Government can give by the employment of the best private manufactories will stimulate improvement, distribute and extend the employment of labour, increase the productive energies of the country, and enlarge their own sources of supply, to any extent which sudden emergency may require.

In the next place, it must occur to many, that while great defensive works have been carried out at Portsmouth and Plymouth, some of our other dockyards and arsenals are left comparatively unprotected, as well as the Thames, the Mersey, the Clyde, the Tyne, and other rivers leading to rich towns, docks, and shipping, and to many great establishments which are or might be made supplementary dockyards and arsenals, and the destruction of which, apart from any direct injury to the public service, would be a terrible public calamity. The Thames, especially, offers the greatest temptation to any hostile fleet, which, even for a few days, might gain possession of the narrow seas.

And, if Forts are to be built at any of these places, may I suggest the inquiry, whether it is necessary that they should be calculated to resist a long siege, and be of such size as to absorb for their defence a large number of men, or whether, as a general rule, it would be sufficient for them to be of small size, and capable of offering resistance to a sudden attack. I do not presume to give an opinion upon this subject, but the great power of our railway system, by which a large force not only of soldiers, but of labourers, might be concentrated rapidly upon any given point, would seem to indicate that any hostile attack, unless made with overwhelming numbers, to be successful, must be so in a few days.

Our Navy for some years past has been in a transition state, but perhaps the time may have arrived when the classification of ships for all the various services may be considered; and if so it may be desirable to settle in the first instance the type best suited for our coast defence; and when this is done, no time need be lost in producing such a number of that type as would strengthen us at the most vital points, and give us the mastery along our own shores. But the instinctive feelings of every Englishman call for the establishment and maintenance of a Navy sufficiently strong to defend not only our Coasts, but our Colonies, and our Commerce; and the

Government which would set itself at once to answer that call, would, I believe, command the support of the majority of the patriotism and intelligence of this country, and would at the same time bring comfort to thousands of deserving workmen and their families, now suffering in grievous want.

In conclusion, let me express my earnest hope that the future of this Institution may be as useful and as prosperous as its first half-century has been. Our limited vision cannot trace the new paths which Science may open out, or the new purposes to which Engineers may have to apply the powers of Nature; but I feel assured that this Institution will supply men of character and intellect, equal to every occasion, and who will join in the Defence of our Country, by contributing to her moral, and material greatness, leaving England's future, with reverent confidence, to the Great Source of all Power and all Intelligence.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.

With the Authors Compts

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ON SOME OF THE

DEVELOPMENTS

OF

MECHANICAL ENGINEERING

DURING THE LAST HALF-CENTURY

A PAPER READ BEFORE THE MECHANICAL SCIENCE SECTION (G)
AT THE FIFTY-FIRST MEETING OF THE BRITISH
ASSOCIATION HELD AT YORK 1881

BY

SIR FREDERICK BRAMWELL, F.R.S.

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I AM quite sure the Section will agree with me in thinking—it was very fortunate for us, and for science generally, that our President refrained from occupying the time of the Section by a retrospect, and devoted himself, in that lucid and clear address with which he favoured us, to the consideration of certain scientific matters connected with engineering, and to the foreshadowing of the directions in which he believes it possible that further improvements may be sought for. But I feel it is desirable that some one should give to this Section a record, even although it must be but a brief and an imperfect one, of certain of the improvements that have been made, and of some of the progress that has taken place, during the last fifty years, in the practical application of mechanical science, with which science and its applications our Section is particularly connected. I regret to say that, in common with most of the gentlemen who sat on this platform yesterday—who I think were, without exception, past Presidents of the Section—I am old enough to give this record from personal experience. Fifty years ago I had not the honour of being a member, nor should I, it is true, have been eligible for membership of the Association; for I was at that time vigorously making models of steam-engines, to the great annoyance of the household in which I lived, and was looking forward to the day when I should be old enough to be apprenticed to an engineer.

Without further preface, I will briefly allude to some of the principal developments of a few of the branches of engineering. I am well aware that many branches must necessarily be left unnoticed; but I trust that the omissions I may make will be remedied by those present who may speak upon the subject after me.

I will begin by alluding to the *Steam Engine employed for manufacturing purposes.* In 1831 the steam-engine for these purposes was commonly the condensing beam-engine, and was supplied with steam from boilers known, from their shape, as waggon-boilers. This shape appears to have been chosen rather for the convenience of the sweeps, who periodically went through the flues to remove the soot consequent on the imperfect combustion, than for the purpose of withstanding the internal pressure of steam. The necessary consequence was, that the manufacturing engines of those days were compelled to work with steam of from only 3½ lbs. to 5 lbs. per square inch of pressure above atmosphere. The piston-speed rarely exceeded 250 feet per minute, and as a result of the feeble pressure and of the low rate of speed, very large cylinders indeed were needed relatively to the power obtained. The

consumption of fuel was heavy, being commonly from 7 lbs to 10 lbs. per gross indicated horse-power per hour. The governing of the engine was done by pendulum-governors, revolving slowly, and not calculated to exert any greater effort than that of raising the balls at the end of the pendulum-arms, thus being, as will readily be seen, very inefficient regulators. The connection of the parts of the engine between themselves was derived from the foundation upon which the engine was supported. Incident to the low piston-speed was slowness of revolution, rendering necessary heavy fly-wheels to obtain even an approach to practical uniformity of rotation, and frequently rendering necessary also heavy trains of toothed gearing to bring up the speed from that of the revolution of the engine to that of the machinery it was intended to drive.

In 1881 the boilers are almost invariably cylindrical, and are very commonly fired internally, either by one flue or by two; and we owe it to the late Sir William Fairbairn, President of the British Association in 1861, that the danger which at one time existed of the collapse of these fire-flues has been entirely removed, by his application of circumferential bands. Now-a-days there are, as we know, modifications of Sir William Fairbairn's bands; but by means of his bands, or by modifications thereof, all internally flued boilers are so strengthened that the risk of a collapse of the flue is at an end. Boilers of this kind are well calculated to furnish, and commonly do furnish, steam of from 40 lbs. to 80 lbs. pressure above atmosphere; the piston-speed is now very generally 400 feet or more, so that, notwithstanding that there is usually a liberal expansion, the mean pressure upon the piston is greater, and this, coupled with the increased piston-speed, enables much more power to be obtained from a given size of cylinder than was formerly obtainable. The revolutions of the engine now are as many as from 60 to 200 per minute, and thus, with far lighter fly-wheels, uniformity of rotation is much more nearly attained. Moreover, engines are now self-contained, and no longer depend upon the foundation for the connection of their parts. In many cases the condensing is effected either by surface condensers, or, where there is not an ample supply of water, the condensation is in a few instances effected by the evaporative condenser—a condenser which, I am sorry to say, is not generally known, and is therefore but seldom used, although between thirty and forty years have elapsed since its first introduction. Notwithstanding the length of time during which the evaporative condenser has been known to some engineers, it is a common thing to hear persons say, when you ask them if they are using a condensing engine, 'I cannot use it, I have not water enough'—a very sufficient answer, indeed, if an injection condenser or an ordinary surface condenser constituted the sole means by which a vacuous condition might be obtained, but a very insufficient answer having regard to the existence of the evaporative condenser, as by its means whenever there is water enough for the feed of a non-condensing engine, there is enough to condense the exhaust steam, and to produce a good vacuum. The evaporative condenser simply consists of a series of pipes, in which is the steam to be condensed, and over which the water is allowed to fall in a continuous rain. By this arrangement there is evaporated, from the outside of the condenser, a weight of water, which goes away in a cloud of vapour and is nearly equal to the weight of steam which is condensed, and is returned as feed

water into the boiler. The same water is pumped up and used outside the condenser over and over again, needing no more to supply the waste than would be needed as feed water, and as the condenser acts by evaporation its effect is practically as good whether the external water be warm or cold. Although this condenser has, as I have said, been in use for thirty or forty years, there are still to be seen engines, working without condensation at all, or with waterworks water, purchased at a great cost, and to the detriment of other consumers who want it for ordinary domestic purposes; or large condensing ponds are used in which the injection water is stored, to be worked over and over again, and frequently (especially towards the end of the week) in so tepid a state as to be unfit for its purpose. The governing is now done by means of quick-running governors, which have power enough in them to raise, not merely the pendulum-balls, which are small, but a very heavy weight, and in this way the governor is extremely effective. I propose to say no more —looking at the magnitude of the whole of my subject—upon the engine used for manufacturing purposes, but rather to turn at once to those employed for other objects.

Steam Navigation.—In 1831 there were a considerable number of paddle-steamers running on some of the rivers in England and across the Channel to the Continent. But there were no ocean steamers, properly so called, and there were no steamers used for warlike purposes. As in the case of the waggon-boilers, the boilers of the paddle-steamers of 1831 were most unsuited for resisting pressure. They were mere tanks, and as tanks the downward strain from the mere weight of water was as great on the bottom plates, even in the absence of any steam-pressure within the boiler at all, as, when the steam was up, was the upward strain on the top plates. Under these circumstances, again, from 3½ lbs. to 5 lbs. on the square inch was all the pressure the boilers were competent to bear, and this feeble pressure, coupled with the slow speed at which the engines ran, caused them to develop but a small amount of horse-power in relation to their size. Moreover, as in the land engine, the connection between the parts of the marine engine was such as to be incompetent to stand the strain that would come upon it if a higher pressure, with a considerable expansion, were used, and thus the consumption of coal was very heavy; and we know, that having regard to the then consumption, it was said, on high authority, it would be impossible for a steam-boat to cross the Atlantic, as it could not carry fuel enough to last out the voyage; and it was not till 1838 that the *Sirius* and the *Great Western* did make the passage. One boat, it is true, had crossed before, but it was not till 1838 that passenger traffic was really commenced. In 1831, owing to the condensation being effected by injection, the marine boiler was supplied with salt water, the hulls were invariably of wood, and the speed was, probably, from eight to nine knots an hour. In 1881 the vessels are as invariably either of iron or of steel, and I believe it will not be very long before the iron disappears, giving place entirely to the last-mentioned metal. With respect to the term 'steel' I am ready to agree that it is impossible to say where, chemically speaking, iron ends and steel begins. But (leaving out malleable cast-iron) I apply this term steel to any malleable ductile metal of which iron forms the principal element, and which has been in fusion, and I do so in contradistinction to the metal which may be similar chemically but which has been prepared by the puddling process. Applying the term steel in that sense, I believe,

as I have said, it will not be very long before plate iron, produced by the puddling process, will cease to be used for the purpose of building vessels. With respect to marine engines these are now supplied with steam from multiple-tubed boilers which are commonly cylindrical. They are of enormous strength and made with every possible care, and carry from 80 to 100 lbs. pressure on the square inch. It has been found, on the whole, more convenient to expand the steam in two or more cylinders rather than in one. I quite agree that, as a mere matter of engineering science, there is no reason why the expansion should not take place in a single cylinder, unless it be that you cool down a single cylinder to an extent which cannot be overcome by jacketing, and which, therefore, destroys a portion of the steam on its entrance into the cylinder. As regards the propeller, as we know, except in certain cases, the paddle-wheel has practically disappeared, and we have the screw-propeller employed, either singly, or in pairs. This substitution of the screw-propeller for the paddle enables the engines to work at a much greater number of revolutions per minute, and thus a piston-speed of some 600 to 800 feet per minute is attained; and this, coupled with the fairly high mean pressure which prevails, enables a large power to be got from a comparatively small-sized engine. Speeds of 15 knots an hour are now in many cases maintained by steam-vessels throughout their voyages, and on trial trips are not uncommonly exceeded. The steam-vessel is now the accepted vessel of war. We have them in an armoured state and in an unarmoured state, but when unarmoured rendered so formidable by the power which their speed gives them of choosing their distance, as to make them, when furnished with powerful guns, dangerous opponents even to the best armoured vessels. We have also now marine engines governed by governors of such extreme sensitiveness as to give them the semblance of being endowed with the spirit of prophecy, as they appear rather to be regulating the engine for that which is about to take place than for that which is taking place. This may sound a somewhat extravagant statement, but it is so nearly the truth that I have hardly gone outside of it, in using the words I have employed. For a marine governor to be of any use it must not wait till the stern of the vessel is out of the water, before it acts to check the engine and reduce the speed; nothing but the most sensitive and indeed anticipatory action of the governor can efficiently control marine propulsion. Instances are on record of vessels having engines without marine governors, being detained by stress of weather at the mouth of the Thames, while vessels having such governors, of good design, have gone to Newcastle, have come back, and have found the other vessels still waiting for more favourable weather. With respect to condensation in marine engines it is almost invariably effected by surface-condensers, and thus it is that the boilers, instead of being fed with salt water as they used to be, involving continuous blowing-off and frequently the salting-up of the boiler, are now fed with distilled water. It should be noticed, however, that in some instances, owing to the absence of a thin protecting scale upon the tubes and plates, very considerable corrosion has taken place, especially where distilled water, derived from condensers having un-tinned brass tubes, has been used for the feed, and where the water has carried into the boiler fat-acids arising from the decomposition of the grease used in the engine; means are now employed by which these effects are counteracted.

I wish before quitting this section of my subject, to call your attention to two very interesting but very differing kinds of marine engines. One is the high-speed torpedo-vessel or steam launch of which Messrs. Thornycroft have furnished so many examples. In these, owing to the rate at which the piston runs, to the initial pressure (120 lbs.), and to very great skill in the design, Messrs. Thornycroft have succeeded in obtaining a gross indicated horse-power for as small a weight as half a cwt., including the boiler, the water in the boiler, the engine, the propeller shaft, and the propeller itself. To obtain the needed steam from the small and light boiler, recourse has to be made to a fan-blast driving air into a closed stoke-hold. From the use of a blast in this way two excellent things happen: one is, as already stated, that from a small boiler a very large amount of steam is produced, and the other that the artificial blast, when thus applied, is unaccompanied by the dangers which arise when, under ordinary circumstances, the blast is applied only to the ash-pit itself. The other marine engine to which I wish to call your attention, is one that has been made with a view to great economy. The principles followed in its construction are among those suggested by the President (Sir W. G. Armstrong) in his address. He—you will remember—pointed out that the direction in which economy in the steam-engine was to be looked for was in that of increasing the initial pressure; although, at the same time, he said, there were drawbacks, in the shape of greater loss by radiation, and by the higher temperature at which the products of combustion would escape. We must admit the fact of the latter source of loss when using a very high pressure of steam, it being inevitable that the temperature of the products of combustion escaping from a boiler under these conditions must be higher than those which need be allowed to escape when a lower pressure of steam is employed; although I regret to say that in practice in marine boilers, working at comparatively low pressures, the products are ordinarily suffered to pass into the funnel, at above the temperature of melting lead.[1] But with respect to the loss by radiation in the particular engine I am about to mention—that of Perkins—there is not so much loss as that which prevails in the ordinary marine boiler, because the Perkins boiler is completely enclosed, with the result that while there is within the case a boiler containing steam of 400 lbs. on the square inch, and the fire to generate that steam, the hand may be applied to the casing itself, which contains the whole of the boiler, without receiving any unpleasant sensation of warmth. By Mr. Perkins' arrangement, using steam of 400 lbs. in the boiler, it was found, as the result of very severe trials conducted by Mr. Rich, of Messrs. Easton and Anderson's firm, and myself—trials which lasted for twelve hours—that the total consumption of fuel, including that for getting up steam from cold water, was just under 1·8 (actually 1·79) lbs. per gross indicated horse-power per hour. That consumption was ascertained in a manner which it is desirable should always be employed in steam-boat trials. It was not arrived at by using as a divisor the horse-power of the most favourable diagram obtained during the day, but it was got from diagrams taken every half-hour during the regular

[1] It should have been noticed, that although the products of combustion must escape from the boiler at a greater temperature where a high pressure of steam is employed than they *need* escape at where a lower pressure is used, it does not follow that loss should accrue on this account, as the excess can, by means of a heater, be taken up by the feed water: a plan Mr. Perkins is employing in practice.

work; then, when the pressure began to die down, from coal being no longer put upon the fire, diagrams taken every quarter of an hour; and then, towards the last, every five minutes; and the total number of foot-pounds were calculated from these diagrams, and were used to obtain the gross indicated horse-power.

Further, so far as could be ascertained by the process of commencing a trial with a known fire, and closing that trial, at the end of six hours, with the fire as nearly as possible in the same condition, the consumption was 1·66 lbs. of coal per gross indicated horse-power per hour, so that, without taking into account the coal consumed in raising steam from cold water, the engine worked for 1⅝ lbs. of coal per horse per hour. I think it well to give these details because, undoubtedly, this is an extremely economical result.

Our President alluded to the employment of ether as a means of utilising the heat which ordinarily escapes uselessly into the condenser, and he gave some account of that which was done by M. Du Tremblay in this direction. It so happened I had occasion to investigate the matter at the time of Du Tremblay's experiments. Very little was effected here in England, one difficulty being the excise interference with the manufacture of ether. Chloroform was used here, and it was also suggested to employ bi-sulphide of carbon. In France, however, a great deal was done. Four large vessels were fitted with the ether-engine, and I went over to Marseilles to see them at work. I took diagrams from them, and found that by this system the exhaust steam from the steam-cylinder, which was condensed by the application of ether to the surface of the steam-condenser (producing a respectable vacuum of 22 inches), gave an ether-pressure of some 15lbs. on the square inch above atmosphere, and that very economical results as regards fuel were obtained. The system was, however, eventually abandoned, owing to practical difficulties. It need hardly be said that ether-vapour is very difficult to deal with, and although ether is light the vapour is extremely heavy, and if there is any leak in the apparatus the vapour goes down into the bilges by gravitation, and being mixed with air, unless due care is taken to prevent access to the fires, there would be a constant risk of a violent explosion. In fact, it was necessary to treat the engine-room in the way in which a fiery colliery would be treated; the light, for instance, was by lamps external to the engine-room, and shining through thick plate glass, while the hand-lamps were Davy's. The Ether Engine was a bold experiment in applied science, and one that entitles Du Tremblay's name to be preserved and to be mentioned as it was by our President. There was another kind of marine engine that I think should not be passed over without notice. I allude to Howard's Quicksilver Engine. The experiments with this engine were persevered in for some considerable time, and it was actually used for practical purposes in propelling a passenger vessel called the *Vesta*, running from London to Ramsgate. In that engine the boiler had a double bottom containing an amalgam of quicksilver and lead. This amalgam served as a reservoir of heat, which it took up from the fire below the double bottom, and gave forth at intervals to the water above it. There was no water in the boiler, in the ordinary sense of the term, but when steam was wanted to start the engine, a small quantity of water was injected by means of a hand pump, and after the engine was started there was pumped by it into the boiler, at each half-